ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil
Copyright © 2013 by ABCM

SOFTWARE TO ANALYZE BIOMASS ENERGETIC EFFICIENCY

Abstract. *The use of biomass energy, a renewable source of energy, is a strategy for the future. A detailed analysis including the cost of raw materials, energy efficiency and pollutant emissions of biomass is rarely described in available literature. The aim of this work is to define an energetically available methodology to develop a software program that permits an analysis of the raw material costs, energy efficiency and pollutant emissions influences in the energy generation process by means of a biomass conversion. To develop this methodology a literature review was made including energy efficiency, pollutant emissions and raw material costs. Equations to analyze the influence of energy efficiency x raw material costs x pollutant emissions were developed to use in the software. It is expected that the software will help in choosing the ideal biomass to use in energy generation process in a way that provides economy for industries and preserves the environment.*

Keywords: *biomass conversion, pollutant emissions, energy efficiency, calorific value.*

1. INTRODUCTION

Energy is essential to the quality of human life and is considered a fundamental input in productive activities, taking an important role in the development of mankind.

The production and consumption of energy has a strong interaction with the environment. The use of fossil fuels leads to the exhaustion of their reserves and the use of renewable resources acts in detriment of their future availability. The use and consumption of energy implies multiple impacts on soil, water and atmosphere, resulting from their production, conversion and use (Hinrichs, 2006).

Biomass is considered a renewable source of energy. It consists of organic substances (vegetable or animal) and is used in energy production by means of a material combustion process. The use of biomass energy is a strategy for the future (Mckendry, 2002).

In the case of Brazil, more than a 25 % of energy consumption is from vegetable source. The National Energetic Balance from the year 2004 shows that from a total of 213 Mtpe, 58 Mtpe were produced from vegetable biomass. Some of that quantity comes from wood and sugarcane.

About 30% of the Brazilian energetic quantity is furnished by a biomass font like wood, sugarcane bagasses (residues), animals residues like the biogas produced on the biodigestors (Quirino, 2002).

The renewable sources represent about 20% of the world total energy consumption, 14% is produced by biomass sources. In Brazil, the proportion of the total energy consumption from biomass sources is about 25% (Ingham, 1999). This information means that the renewable source can provide about 2/3 of the energy consumption in Brazil.

Each kind of biomass has properties like a combustion material and the pollutant emissions of the biomass process, including toxic gas emissions and energy quantities become an environmental problem (Obernberg, 2004).

The biomass can be divided into three categories: solid, liquid and gas. The solid biomass is formed by agriculture residuals (including vegetable and animals substances), the wood residuals and the fraction of biodegradable industrial residues (Hinrichs, 2006).

The liquid biomass is present on a series of liquid biocombustible with possibility to be used, like biodiesel from sunflower seed oil, ethanol from carbon hydrates fermentation process (sugar, starch, cellulosic) and methanol, produced by natural gas synthesis.

The gaseous biomass can be formed in agroindustrial effluents. It is also present on the landfill (solid residues from cities). This is a result of anaerobic biological degradation of organic materials and is a mixture of methane and carbonic gas. Those materials are submitted to a combustion process to produce energy (Rajvanshi, 1986).

There are advantages in using biomass energy: it's a renewable energy, it's partially pollutant, and there are not CO_2 emissions; it is an economical way of production.

The disadvantages in the use of biomass are: destruction of wood reserves, destruction of natural habitats, smaller heat content values when compared to other energy sources, the liquid biomass energy source may result in acid rain, some difficulties in energy transportation and solid biomass storage (Mckendry, 2002).

Since 1990, the Brazilian agro-business has grown significantly in the international scenario and it is consolidated as one of the largest producers and exporters of food around the world. According to the Ministry of Agriculture, Livestock and Food Supply (MAPA) of Brazil, at the beginning of 2010, one in every four products in the international agro market was a Brazilian product, and it was forecasted that by 2020, Brazilian agro-products will be one-third of the global trade. Hence, the generation of residues in the agricultural sector will grow in the same scale.

In recent years, from a quantitative perspective, the major agricultural productions in Brazil were sugarcane, soybean, rice, wheat and beans. For the selvicultural sector the eucalyptus round wood had an important performance in 2009. The total production of the main Brazilian agricultural products in these years is presented in Fig. 1.

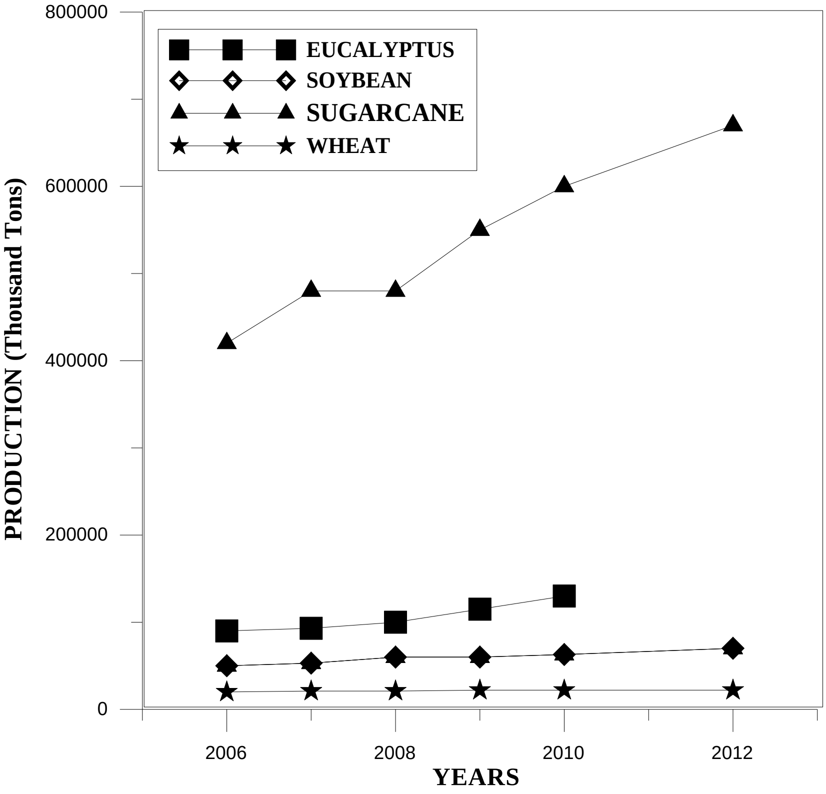


Figure 1: Brazilian agricultural products.
Source: Author's elaboration based on CONAB and ABRAF.

This paper aims to analyze the advantages and disadvantages in the use of the biomass like raw material costs, pollutant emissions of biomass and heat content values. The present work is concerned with defining an energetically available methodology to develop a software program that permits an analysis of the raw material costs, energy efficiency and pollutant emissions influence in the energy generation process by means of a biomass conversion.

2. METHODOLOGY

Biomass energy is that energy derived from living matter such as field crops, trees, and water plants; it is also agricultural and forestry wastes, and municipal solid wastes. Biomass can be used as fuel in three forms:

- Solid biomass fuels produced from wood chips;
- Liquid fuels produced from solid biomass through chemical or biological action and/or conversion of plant sugars to ethanol or methanol;
- Gaseous fuels produced by high temperature and high pressure processing.

Processes for the conversion of biomass into other energy forms are numerous, but can be classified into three types:

a) Biochemical process: the decomposition of organic wastes in an oxygen deficient atmosphere with the production of methane gas (anaerobic digestion), or controlled fermentation for production of the alcohols ethanol and methanol.

b) Direct combustion: the burning of biomass to produce heat for space heating or for the production of electricity through a steam turbine. Anything from solid wastes to crop residues to wood can serve as fuel for this process.

c) Pyrolysis: the thermal decomposition of wastes into a gas or liquid (with a relatively low heating value) under high temperatures in a low oxygen atmosphere.

ISSN 2176-5480

In order to improve a calculated methodology, to provide a software program that permits an analysis of the energy generation process by means of a biomass conversion, a literature review was made referring to biomass energy potential. By the use of the software program an analysis can be performed of the following system responses:

1. Energy generation processes based on the cost of raw materials, calorific values (HCV or LCV), biomass residue and pollutant emissions;
2. Economy based on the acquisition costs of biomass;
3. Pollutant emissions reduction performed by the energy generation process.

To develop this methodology, a literature review was made to select appropriate equations to determine biomass calorific values (HCV or LCV), KJ/Kg or Kcal/Kg and to determine the pollutant emissions quantities by each biomass category.

Considering the biomass acquisition costs (raw materials) in the region of Minas Gerais state, a data table was elaborated. An algorithm was elaborated to permit a final analysis.

2.1 Software Program

In order to demonstrate the capacity of the software program, measurements were carried out based on sequence events that input:

a) The costs of raw materials (acquisition costs of biomass);
b) Material calorific values (HCV or LCV);
c) Material pollutant emissions quantities.

The software program can estimate and optimize the better relation performed by calorific values x raw material costs x pollutant emissions in order to select a biomass to produce energy by means of direct combustion systems.

To demonstrate the methodology performance developed to build the software program, four variables were selected in this study, biomass calorific value, raw material cost, pollutant emissions and biomass residues.

2.1.1 Biomass Calorific Value

In this category, the HCV and LCV values can be used being the same for each biomass and in the same unit system (KJ/Kg or Kcal/Kg). In order to determine a variable to be analyzed, the minor HCV or LCV value is chosen and each HCV/LCV value is divided by this minor value. The results can be varied from one to infinity and a plus signal is adopted for this category, based on the fact that the higher the HCV/LCV values, the higher the biomass efficiency for energy generation process. The most common unit used to HCV/LCV is KJ/Kg or Kcal/Kg. Figure 2 shows HCV (Mcal/Kg) for different biomasses.

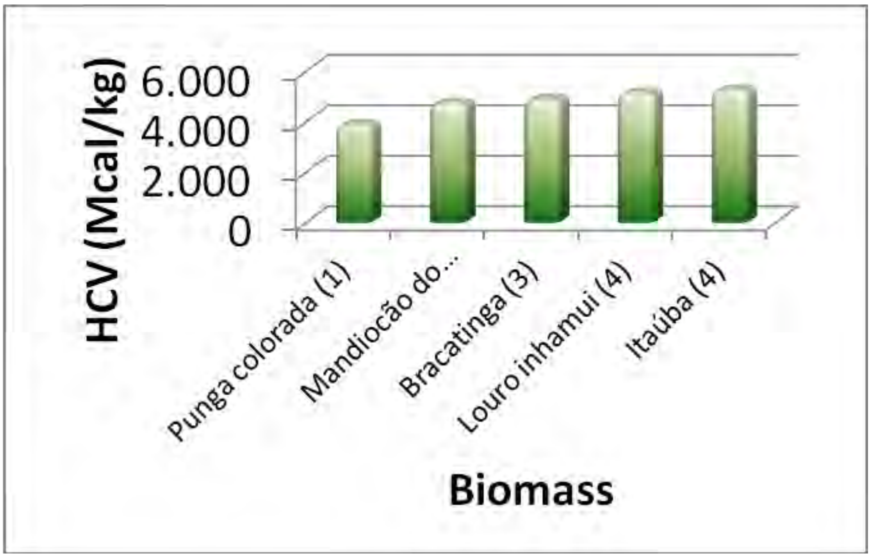


Figure 2: Calorific values (HCV) for selected biomasses: (1) wood, (2) briquettes of wood waste mixed with rice hulls, (3) bark, (4) wood with bark.

2.1.2 Raw Material Costs

In this group of variables the costs of each raw material can be divided by the biomass quantity (Kg). The cost value can be zero. In order to determine the cost value to be analyzed, the minor cost is identified and each one is divided by this minor value, since it is different to zero. The results can vary from one to infinity and a minus signal is adopted for this category, based on the fact that the higher the cost, the lower the biomass efficiency. The unit adopted for this group is R$/ton or R$/m^3.

2.1.3 Pollutant Emissions

The values of the variables in this group were based on TLV (Threshold Limit Value) of a substance, according to ACGIH published tables adapted on NR15. The value of the pollutant emission must be zero and in order to determine the variable to be analyzed, the minor value (different to zero) is identified and each biomass concentration pollutant is divided by this minor value.

2.1.4 Biomass Residue

If the biomass is a residual species, the information is YES to the program, and if not it is NO. For residual biomass the value must be one and if not the value is zero.

The final note or score for each biomass is the sum of the four group scores of variables described above. The program selects the biomass with the higher score.

3. RESULTS

Using the software program developed to estimate the main values of the biomasses selected for analysis, one can decide what type of biomass is the best. To illustrate the complete operation of the software, the results given next were prepared for three different biomasses: rice hull, sugarcane bagasse and wheat straw.

The variables selected as input data for each biomass type are shown on Tab. 1.

Table 1: Biomasses selected values to be used on the software.

Variable	RICE HULL	SUGARCANE BAGASSE	WHEAT STRAW
LCV(KJ/Kg)	14,159.083	13,388.800	13,388.800
HCV(KJ/Kg)	15,778.680	15,480.800	14,926.170
Pollutants			
CO (%)	16.10	16.50	15.50
CH_4 (%)	0.95	0.00	0.00
Pb (%)	0.00	0.00	0.00
Residue	Yes	Yes	Yes
Costs (R$/ton)	70.00	30.00	230.00

The biomass values presented in Tab. 1 were selected as input data for the software based on a literature review. The costs values must vary depending on the period in a year.

3.1 Calorific Value Score

In order to determine the HCV or LCV score, all the values were analyzed and the lesser of them is selected. In the case of the LCV, the lesser value is 13,388.800 KJ/Kg. In the sequence, all the LCV values were divided by the lesser value, respectively. In the case of HCV, the lesser value is 14,926.170 KJ/Kg. The final score determined for CV values is the medium value of the two scores. The results obtained were shown on Tab. 2.

Table 2: The scores calculated to HCV and LCV values.

	RICE HULL	SUGARCANE BAGASSE	WHEAT STRAW
LCV Score	1.0575	1.0000	1.0000
HCV Score	1.0560	1.0364	1.0000
Final Score	1.0568	1.0182	1.0000

3.2 Costs Score

The raw material costs score is determined in the same way as the HCV/LCV values, the lesser value present on Tab. 1 is selected and all the other costs are divided by it. The zero value is not considered in the analysis. A negative signal is adopted here to indicate how much worse this category is. The results were presented in Tab. 3.

Table 3: Biomass Costs Score.

	RICE HULL	SUGARCANE BAGASSE	WHEAT STRAW
Costs Score	2.333	1.000	7.667
Final Score	-2.333	-1.000	-7.667

3.3 Pollutants Score

In order to find a score for the pollutants group, the lesser pollutant value is considered in Tab. 1. If there is a zero value in this category the next is considered and all the pollutants notes were divided by it. The partial results can be seen in Tab. 4.

Table 4: Pollutants Score.

	RICE HULL	SUGARCANE BAGASSE	WHEAT STRAW
Partial Score CO	1.0387	1.0645	1.0000
Partial Score CH_4	1.0000	0.0000	0.0000
Partial Score Pb	0.0000	0.0000	0.0000

Accordingly to ACGIH, TLV of a substance is a level to which it is believed a worker can be exposed day after day for a lifetime work without adverse health effects. Some substances have a ceiling limit which shall not be exceeded even momentarily or infrequently and the degree of unhealthiness is defined as maximum and minimum. The results about these notes are presented in Tab. 5.

Table 5: Danger Level and ceiling limit values for the pollutants.

Pollutants	Ceiling Limit	mg/m^3 to 48 h/weekly	Degree of Unhealthiness
CO	NO	43.00	MAXIMUM
CH_4	NO	0.00	NOT DEFINED
Pb	NO	0.10	MAXIMUM

To investigate the influence of each one of the variables mentioned above, different weights for each variable were established. These weights must be defined according to their variable importance in the energy generating process. In the case of the ceiling limit, the weight 1.000 is assumed for the pollutants with NO ceiling limit and weight 2.000 for the cases within a specified ceiling limit value. Considering the concentration values defined as mg/m^3 to 48 h exposition, the weights are shown in Tab. 6.

Table 6: Weights defined for weekly concentration exposition.

Pollutants	mg/m^3 to 48 h/weekly	Weights
CO	43.00	1
CH_4	0.00	0
Pb	0.10	2

The weights created to a degree of unhealthiness are presented in Tab. 7.

Table 7: Weights defined for degree of unhealthiness.

Degree of Unhealthiness	Weights
NOT DEFINED	0.000
MINIMUM	1.000
MEDIUM	2.000
MAXIMUM	3.000

The final results concerning the weights are presented in Tab. 8.

Table 8: Weights defined for use in the software program.

Pollutant	Ceiling Limit	Factor	mg/m^3	Factor	Degree of Unhealthiness	Weights
CO	NO	1,000	43.00	2,00	MAXIMUM	3,00
CH_4	NO	1,000	0.00	0,00	NOT DEFINED	0,00
Pb	NO	1,000	0.10	3,00	MAXIMUM	3,00

The total weights for each pollutant were defined as the multiplication of all weights, as presented in Tab. 9.

Table 9: Total weights for pollutants.

Pollutant	Ceiling Limit	mg/m^3	Degree of Unhealthiness	Total weights
CO	1,000	2,000	3,000	6,000
CH_4	1,000	0,000	0,000	0,000
Pb	1,000	3,000	3,000	9,000

Before the partial score and the total weights were defined for each pollutant, we multiplied them to find the pollutant final score to be used in the analysis.

The next step is to divide the pollutant final score by the pollutant quantity present in the analysis. As the pollutant presence in the energy generation process by means of a biomass conversion is undesirable, a minus signal was adopted for the final score. The pollutant final score is presented in Tab. 10.

Table 10: Pollutant final score calculated by the software.

	RICE HULL	SUGARCANE BAGASSE	WHEAT STRAW
Pollutant Final Score	-2.0774	-3.7634	-2.000

The last variable to analyze is the biomass residue. If the biomass selected for use in the energy generation process is considered residual material, its score will be higher. The results are presented in Tab. 11.

Table 11: Residue Final Score.

<table>
<tr><th colspan="3">IS THE BIOMASS A RESIDUE?</th></tr>
<tr><td colspan="2">YES</td><td>NO</td></tr>
<tr><td>SCORE</td><td>1,000</td><td>0,000</td></tr>
</table>

Table 12: Biomass final scores calculated on the software program.

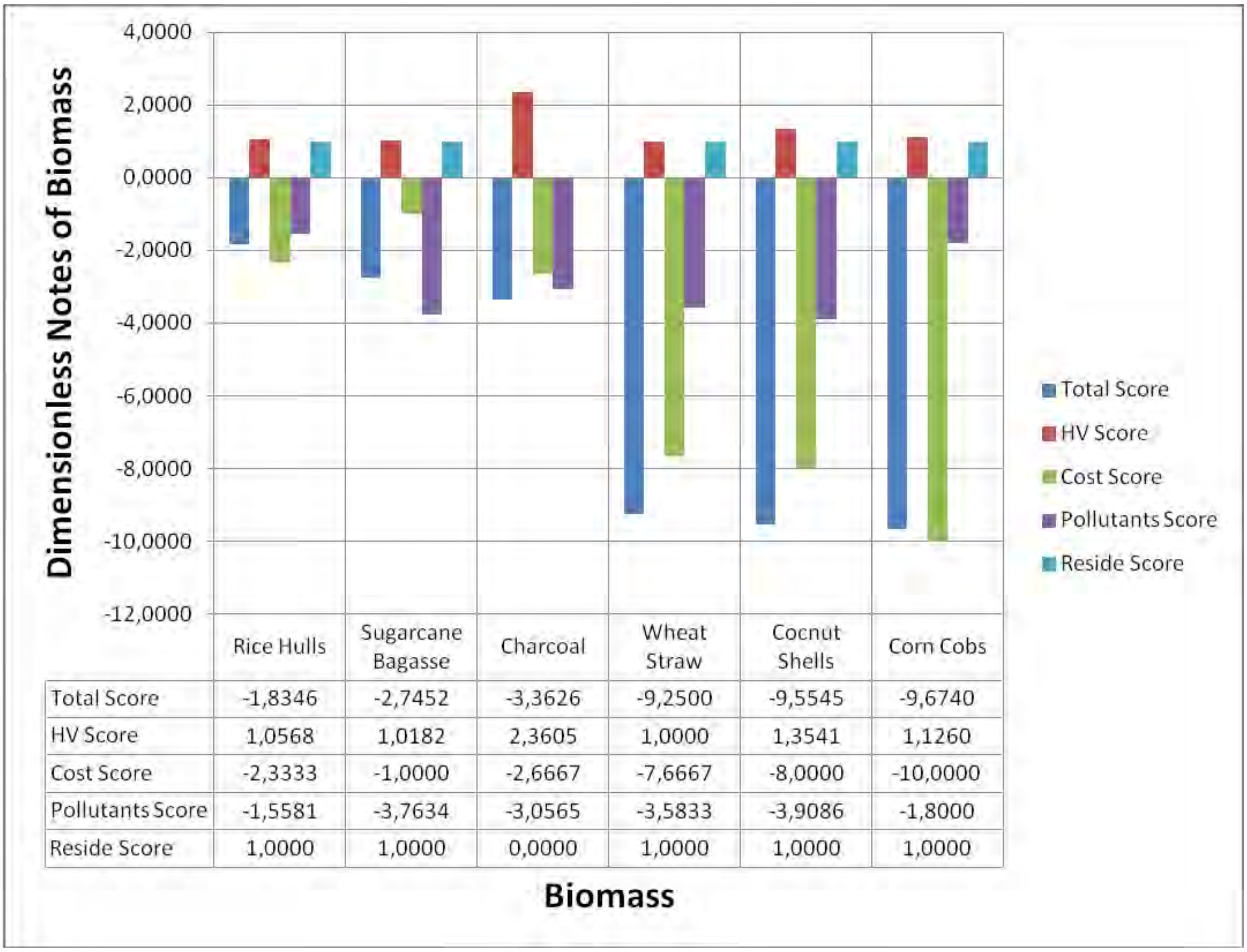
Final Score	% Importance	RICE HULL	SUGARCANE BAGASSE	WHEAT STRAW
HCV/LCV	25	1,0568	1,0182	1,000
COSTS	25	-2,3333	-1,000	-7,667
POLLUTANTS	25	-2,0774	-3,7634	-2,000
RESIDUE	25	1,000	1,000	1,000
FINAL SCORE	100	-1,8346	-2,7452	-7,667

The results presented in Tab. 12 shows that the rice hull was the biomass with higher final score and is the biomass indicated to use in an energy generation process by direct combustion.

As presented before, direct combustion is based on the burning of biomass to produce heat for space heating or for the production of electricity through a steam turbine.

Using the software program to simulate the performance of a biomass, six different types of biomasses were selected as input data: rice hulls, sugarcane bagasse, charcoal, wheat straw, coconut shells and corn cobs. All information necessary to simulate the biomass performance was taken on a literature review.

To run the program, the same % of importance was adopted to each biomass. The results are shown in Fig. 3.



	Rice Hulls	Sugarcane Bagasse	Charcoal	Wheat Straw	Cocnut Shells	Corn Cobs
Total Score	-1,8346	-2,7452	-3,3626	-9,2500	-9,5545	-9,6740
HV Score	1,0568	1,0182	2,3605	1,0000	1,3541	1,1260
Cost Score	-2,3333	-1,0000	-2,6667	-7,6667	-8,0000	-10,0000
Pollutants Score	-1,5581	-3,7634	-3,0565	-3,5833	-3,9086	-1,8000
Reside Score	1,0000	1,0000	0,0000	1,0000	1,0000	1,0000

Figure 3: Dimensionless Notes of Biomasses.

Accordingly to Fig. 3, the total score indicates that rice hulls are the biomasses recommended to the energy generation process. The rice hulls total score was -1,8346. By the same way, the corn cobs biomass was appointed the lower score, with total score -9,6740 and is not recommended to use on energy generation process.

4. CONCLUSIONS

In the first stage of this study, using general information about biomasses, a methodology was developed to perform a detailed analysis including the cost of raw materials, energy efficiency and pollutant emissions of biomass. Equations to analyze the influence of energy efficiency x raw material costs x pollutant emissions were developed to use in a software program.

In the next stage, a software program was elaborated to permit an analysis of the energy generation process by means of a biomass conversion.

The operation of this software program to provide biomass analysis was simulated using three types of biomass to explain and illustrate the methodology, rice hulls, sugarcane bagasses and wheat straw. The results obtained indicate that the rice hull is the biomass with higher final score, and is the indicated biomass to use in an energy generation process based on combustion reactions.

It is expected that the software program developed here will help in choosing the ideal biomass to use in the energy generation process in a way that provides economy for industries and preserves the environment.

5. REFERENCES

ABNT, 2012. "NBR 8633: Carvão vegetal: determinação do poder calorífico – Método de ensaio". 25 Oct. 2012 <http://www.abcntcatalogo.com.br>.

Brand, M.A. and Muñiz, G.I.B., 2010. Influência da época de colheita da biomassa florestal sobre sua qualidade para a geração de energia. Sci. For., Piracicaba, v. 38, n. 88, p. 619-628.

Brito, O.J., Ferreira, M. and Barrichelo, L.E.G., 1978. "Correlações entre características físicas e químicas da madeira e a produção de carvão vegetal. II. Densidade básica da madeira x densidade aparente do carvão – perspectivas de mehoramento". Boletim Informativo ESALQ/USP, v. 6, n. 16, p. 1-9.

Castillo, M.E.U., 1994. Determinacion del poder calorífico de 20 espécies florestales de la Amazonia peruana. *Revista Florestal do Peru,*Vol. 12, n. 1-2, p. 98-117.

Diniz, J., Cardoso, A.L., Stahl, J.A., Villetti, M.A. and Martins, A.F., 2004. Poder calorífico da casca de arroz, caroço de pêssego, serragem de e Educalipto e de seus produtos de pirólise. *Ciência e Natura*, UFSM, 26(2):25-32.

Goldemberg, J., 1998. Energia, meio ambiente e desenvolvimento. São Paulo: Editora da Universidade de São Paulo.

Hinrichs, R.A. and Kleinbach, M., 2006. Energy: Its Use and the Environment, 4th Edition, Thomson Brooks/Cole.

Ingham, J.M., 1999. Biomassa no mundo e no Brasil. In: Fontes não-convencionais de energia: as tecnologias solar, eólica e de biomassa. 2a ed., Florianópolis: Editora da UFSC.

Mckendry, P., 2002. "Energy production from biomass (part 1): overview of biomass". *Science, Bioresource Technology*, Vol. 83, p. 37-46.

Obernberg, I. and Gerold, T., 2004. "Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behaviour". *Science, Biomass and Bioenergy*, Vol. 27, Issue 6, p. 653-669.

Quirino, W.F. at all, 2005. "Poder calorífico da madeira e de materiais ligno-celulósicos". *Revista da Madeira n° 89*, p. 100-106.

Quirino, W.F., 2002. "Utilização energética de resíduos vegetais". Brasília: Laboratório de Produtos Florestais, IBAMA.

Pinto, A.L.T. (Organizador), 2008. Segurança e Medicina do Trabalho, 2a Edição, Saraiva.

Rajvanshi, A.K., 1986. Biomass Gasification. Published as a Chapter (N° 4) in book *Alternative Energy in Agriculture*, Vol. II. Ed. D. Yogi Goswami, CRC Press, p. 83-102.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.